DESIGN AND OPERATION CONSIDERATIONS FOR AERATED LAGOONS IN THE ARCTIC AND SUBARCTIC

Report No. 102

by

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INTRODUCTION

Between 1964 and 1967 the Environmental Engineering Section of the Arctic Health Research Center, supported by the Alaskan Air Command of the U. S. Air Force, and in cooperation with the Federal Aviation Agency, studied operating characteristics of four aerated sewage lagoons in Alaska (1, 2, 3). Three of the four lagoons were operated as primary-secondary treatment units receiving raw sewage from Federal Aviation Agency sites at Northway, Cold Bay, and Bethel, Alaska. Their locations, operating conditions and ambient temperatures were presented in the referenced papers. The fourth lagoon, at Eielson Air Force Base, operated from October 1964 through July 1965 as a secondary treatment unit receiving a portion of the effluent from the primary treatment plant at the base. During the winter months the loading rates on the Eielson lagoon were varied from 0.4 to 3.1 lbs/1000 ft^3/day in an effort to determine optimum loading conditions for that season. Results of this study were reported in an earlier paper (2). From this information, design criteria were developed for the construction and operation of the lagoon as a secondary treatment unit.

As the need for more economical waste treatment systems for the North became apparent, the emphasis of the Environmental Engineering Section changed to lagoons for receiving raw sewage. Consequently, in September 1965, the lagoon at Eielson Air Force Base was converted to receive raw sewage. Figure

1 presents a plan of this (typical) lagoon. Studies were also made to deter oxygen uptake in the bottom sludge of the aerated lagoons. In addition to e pilot plant operation, parallel studies were conducted using a Warburg re ometer for oxygen uptake measurements along with conventional BOD ana to determine the extent of biological activity in waste treatment during ex winter temperatures.

MECHANICS OF LAGOON OPERATION

In reality the aerated lagoon as developed by Hinde (12) is a composite sys utilizing the effects of sedimentation, activated sludge, anaerobic sludge d tion and extended aeration. As the sewage enters the lagoon, it spreads o ward from an inlet pipe allowing suspended matter to settle as the velocity decreases. Some of the smaller particles are kept in suspension by the ri air bubbles. As they come into contact with other sewage particles and or isms, activated sludge forms and eventually settles to the bottom. The set sludge digests anaerobically when the sludge depth is sufficient to restrict oxygen supply. During the winter months the digestion rate is slowed, cau sludge accumulation until early summer when lagoon temperatures are mor favorable. Then the sludge digests, the anaerobic by-products diffuse into oxygen-laden water and there they are further removed by the suspended or ganisms and gas stripping.

Since the aerated lagoon contains characteristics of several waste treatmen systems, it is difficult to apply to them the equations and reactions used to explain these other systems. So long as sufficient air is supplied to keep th system aerobic, and loads are applied at rates that allow the biologic popula tion to expand to meet the available food supply, the minimum efficiency of t

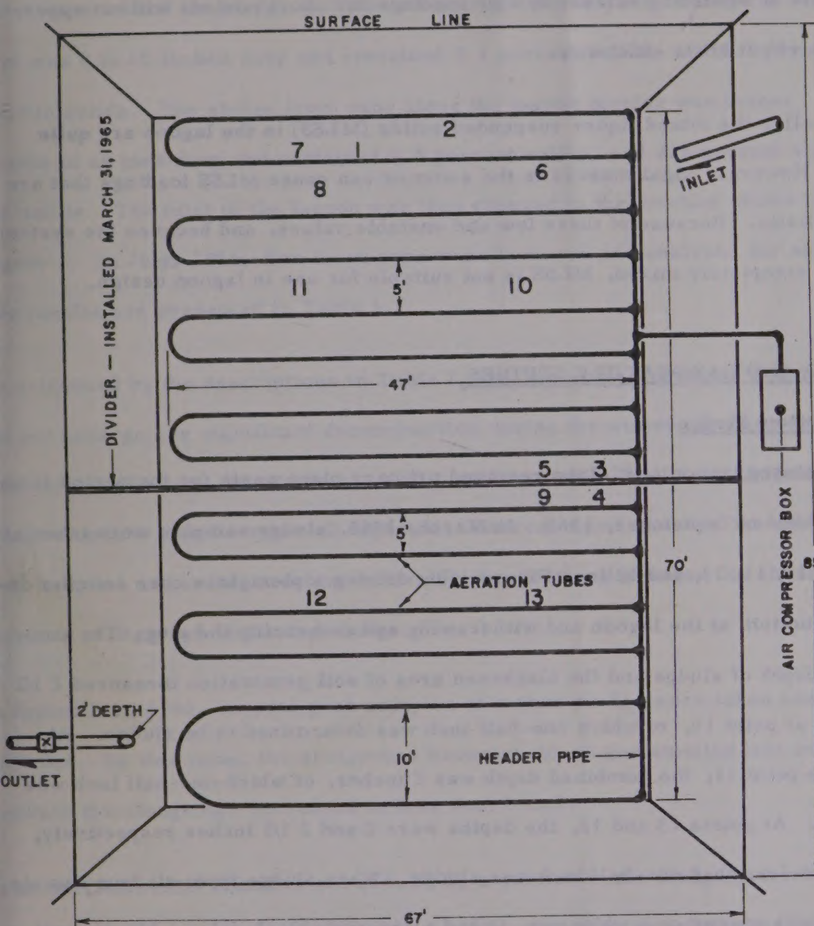


FIGURE 1. PLAN OF AERATED LAGOON AT EIELSON AIR FORCE BASE

system will fall between 45 percent and 65 percent--the upper and lower rang for sedimentation and activated sludge systems respectively. These removal will occur at detention times of less than one day. The system is, therefore, capable of absorbing extremely high loadings for short periods without appreciable effect onits efficiency.

Normally, the mixed liquor suspended solids (MLSS) in the lagoon are quite low. However, algal masses in the summer can cause MLSS loadings that are unrealistic. Because of these low and unstable values, and because the systen is not completely mixed, MLSS is not suitable for use in lagoon design.

FIELD AND LABORATORY STUDIES

A. Bottom Sludge

The aerated lagoon at Eielson received primary plant waste for the period from July, 1964 to September, 1965. In March, 1965, sludge samples were taken at points 10, 11, 13, and 12 (see Figure 1) by driving a plexiglass core sampler into the bottom of the lagoon and withdrawing and measuring the plug. The combined depth of sludge and the blackened area of soil penetration measured 2 1/2 inches at point 10, of which one-half inch was determined to be sludge. At sample point 11, the combined depth was 2 inches, of which one-half inch was sludge. At points 13 and 12, the depths were 2 and 2 1/8 inches respectively, of which less than one-half inch was sludge. When sludge from all four sample points was spread on a white pan, it had a greenish-black color. Microscopically it contained numerous embryo algal forms.

In November, 1965, 2-inch-deep metal pans were placed in the bottom of the lagoon and marked with buoys. The locations of pans 1, 2, 3, 4, 7 and 8 are

own in Figure 1. At that time, the inlet of the lagoon was located between nts 1 and 2. In April, 1966, after remaining in the lagoons for approximate- five months, two of the inlet pans and a pan from each side of the divider re removed and the sludge samples measured and analyzed. Sludge at the et was 8 to 10 inches deep and contained 9.1 percent solids, and 8.7 percent latile solids. The sludge from pans along the lagoon divider was three- ırths of an inch deep and contained 4.5 percent solids, and 2.5 percent vola- e solids. The inlet of the lagoon was then changed to the location shown in gure 1. In July, 1966, five more pans were removed and analyzed for solids. ıe results are presented in Table 1.

s evidenced by the descriptions in Table 1, the raw sludge at points 1 and 2 d not undergo any significant decomposition during the winter months. It was ill typical of sludge from primary sedimentation, while the finely divided udge at points 3 and 4 was well digested. Between April and July the sludge om points 1 and 2 underwent considerable digestion and attained the charac- ristics of digested, activated sludge.

September, 1966, several grab samples of bottom sludge were taken near e inlet. By this time, the sludge was brownish-black and smelled like humus. epth of the sludge had decreased to less than 1 inch.

ı an environmental chamber set at 0.5° C, a portion of the sludge gathered om points 1 and 2 in April, 1966, was further tested to determine the degree f oxygen uptake at near-freezing temperature. The apparatus used in this tudy was described by McKinney (4). The sludge was placed in two bottles to epths of 2 inches (5.1 cms) and 3 inches (7.6 cms) respectively to simulate ludge deposition conditions near the lagoon inlet. The surface area in each

Table 1 - Solids Analyses from the Aerated Lagoons
Eielson Air Force Base, Alaska.

Date	Sample Number	Odor	Color	Per Cent Solids	% Volatil Matter In Solids
4/06/66	1-2	Fresh Sewage	Grey	9.1	90
	3-4	Earthy	Brownish Black	4.5	55
7/15/66	5	Earthy	Brownish Black	3.8	77
	6	None	Brownish Black	8.3	65
	7	None	Golden Brown	4.2	93
	8	None	Golden Brown	3.6	92
	9	Earthy	Brownish Black	4.3	85

Table 2 - Oxygen Uptake Rates at 0.5°C for Sludge from an Aerated Lagoon. -gm/day/cm^3

Day	40 liter/hour	20 liter/hour
0	.0062	.0014
3	.0024	.0006
6	.0021	.00014
21	.0007	.00003

was 28.3 square inches (132 cm^2). Oxygen saturated water was passed over the surfaces of the sludge. The oxygen uptake was measured and the rates were calculated and tabulated in Table 2. The oxygen uptake rate for the sludge is related to the difference in oxygen concentrations in the sludge and overlying liquid, and the difference in anaerobic end-product concentrations in the sludge and water (4). Oxygen uptake still continued even after flushing was discontinued on the twenty-first day. This study demonstrated that even at near-freezing lagoon temperature sludge in an aerated lagoon does undergo digestion, albeit slowly.

B. Oxygen Uptake Study

During the winters of 1965 and 1966 a series of tests were run to better understand the treatment mechanism that occurs in the lagoon during the winter. The first series of experiments consisted of long-term BOD studies run at 0.5° C and 20° C. These studies showed that at low temperatures the BOD increased when lagoon organisms were introduced into the sample.

The second series of tests was run on a Warburg respirometer using raw and sterile sewage as the substrates, and organisms centrifuged from the lagoon effluent. The organisms were placed in the Warburg apparatus and fed sterile, raw sewage for two weeks to acclimate them to the substrate and 0.5° C tem-

perature.

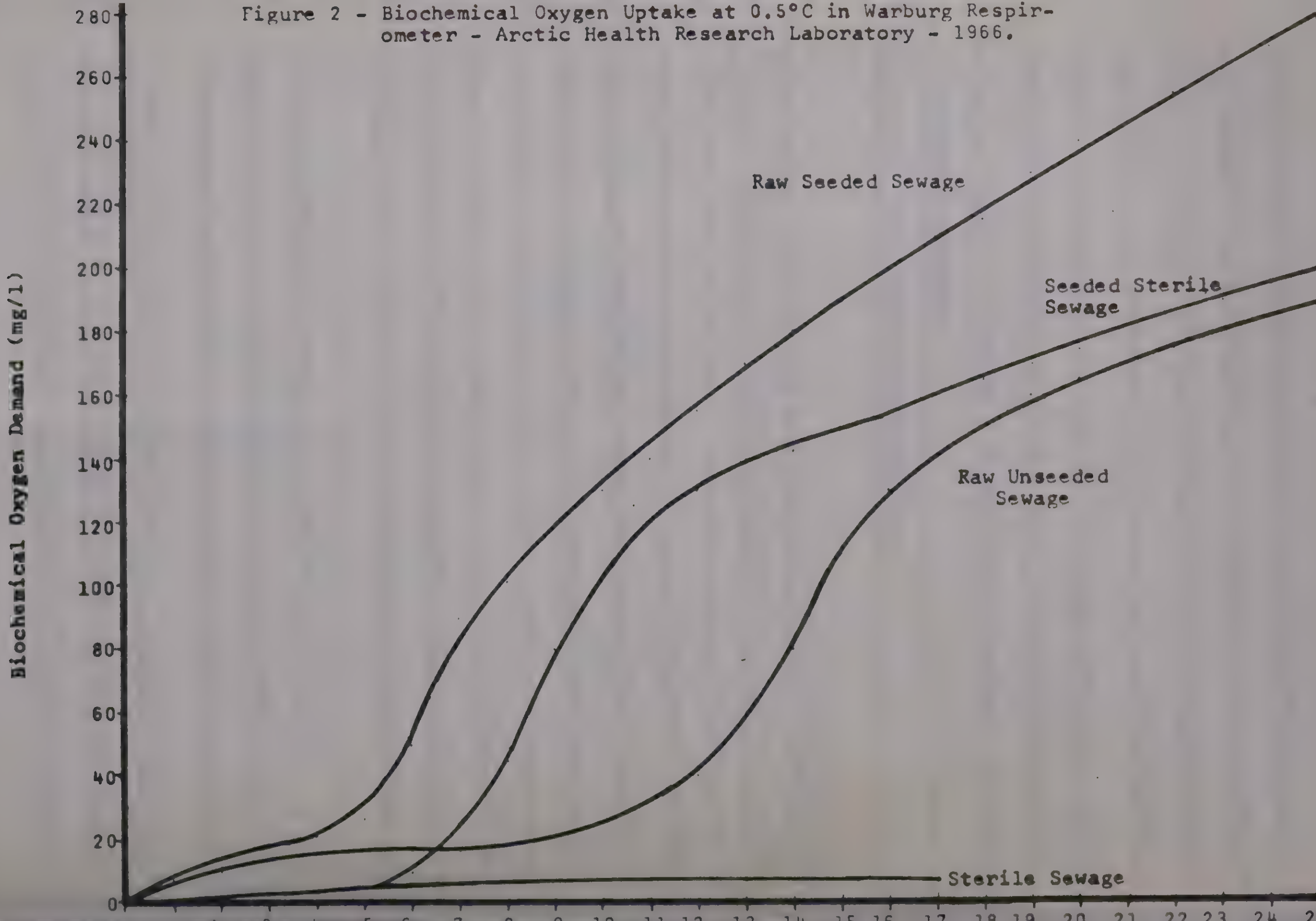
Calibration of the Warburg apparatus was as described by McKinney (5), and techniques for operation of the Warburg and use of manometer fluids were as described in the Handbook of Manometric Techniques (6). The only variation in the apparatus used was the addition of a fiberglass strip to the potassium hydroxide well to act as a wick for better carbon dioxide absorption.

The acclimated seed organisms described earlier were taken from the Warburg and centrifuged until most of the biological mass had settled. The supernate was decanted and the remaining liquid and organisms were all mixed and added in one-tenth ml aliquots to those flasks requiring seed. Flasks were set up containing raw sewage without seed, raw sewage with seed, sterilized sewage with seed and sterilized sewage without seed. Twenty ml of substrate was placed in each flask. Two thermobarometers were set up to determine barometric changes. Readings were taken every two days for periods up to 30 days.

Examples of some of the BOD curves are presented in Figure 2. A four-to six-day lag in the uptake rates will be noted. There was some BOD removal during this time (7 to 12 percent), at a fairly high K rate that ranged from 0.13 to 0.22. However, since these rates were only found in five of the flasks, and the removal was only about 10 percent of the total BOD removed, the K's were not considered in the development of the BOD removal curves discussed later in this paper.

The BOD data obtained from the Warburg was examined to determine the deoxygenation constant K, using the method outlined by Tsivoglou (7). A computer program was written for the least squares fit of the data and for the calculation

Figure 2 - Biochemical Oxygen Uptake at 0.5°C in Warburg Respirometer - Arctic Health Research Laboratory - 1966.



of K values. The K for the raw sewage ranged from 0.026 to 0.105 with an 80 percent probability of values greater than 0.036, and a 60 percent probability that the value would be greater than 0.056. The mean value of K was 0.063.

The literature indicates that the nitrification rate is so reduced at below 9° C that the effect would not be seen until around 60 days. Therefore, the K's reflect only the removal of carbonaceous substances (8, 9, 10, 11).

A calculation of θ for the van't Hoff-Arrhenius equation, based on the mean K (0.063) found in the 0.5° C respirometer studies and a mean K (0.225) found from studies of sewage at 20° C, gives a value of 1.072. This value falls near the values found by Gottas for the 5° to 10° C range. Thus it appears that the organisms present in subarctic lagoons are probably not psychrophillic but are organisms that have their highest reaction rates at normal sewage temperatures. Apparently there is some adaptation, however, as shown by the higher θ.

Therefore, loading rates for lagoons in the summer, when lagoon temperatures are between 16° to 20° C, could be about four times the winter or design loadings.

FIELD STUDY AND DESIGN CONSIDERATIONS

A. Monitoring Techniques

The most common monitoring tool is the BOD removal efficiency. In this test a diluted sample of sewage is incubated at 20° C for a five-day period and the Biochemical Oxygen Demand (BOD) is calculated. The effluent 20° C, five-day BOD is compared with the influent 20° C, five-day BOD to arrive at the plant efficiency. Probably the only time the sewage was at 20° C during this study was somewhere in the sewer and again in the BOD bottle. In the lagoon, the temperature is near freezing during the entire winter. In fact, experience in

Alaska indicates that a lagoon temperature rarely approaches the 20° C at any season. All removals take place in a regime that is lower than the standard test temperatures of 20° C. Therefore, the lagoon effluent consists of organisms that normally live at low temperatures and organisms that normally live in the human body but can survive at low temperatures. A five-day, 20° C BOD will not reflect their true ability to reduce wastes. For example, samples taken from the Eielson lagoon and incubated for five days at 0.5° C had practically no oxygen demand, while the same sample, incubated for five days at 20° C, had a 40 mg/l BOD. The removal efficiencies of the lagoon would thus appear to approach 100 percent.

Practically speaking, the winter-time conditions of a receiving stream are very low temperatures and low dissolved oxygen concentrations. Streams are extensively iced, so aeration is negligible. The lagoon effluent, however, may contain up to five mg/l of dissolved oxygen and a negligible BOD load at ambient conditions. Therefore, one would expect conditions in the stream to be greatly improved by the aerated effluent.

There are many fallacies in the use of the 20° C, five-day BOD, and these have been hashed and rehashed by others. It is enough, here, to say that there is a need for measuring devices which are more representative of arctic and subarctic conditions. If the standard five-day, 20° C BOD test is used, its limitations should be kept in mind.

B. Detention Time

At the Eielson, Northway and Bethel lagoons, there were 30 sampling periods when lagoon temperatures were below 1° C. Data from these samplings was selected as the winter operating condition, and is presented in Figures 3 and 4.

Figure 3 - Efficiency of Winter Operation for Different Detention Times as Compared to Theoretical Removals Based on K Rates Found in a Low Temperature Warburg Study.

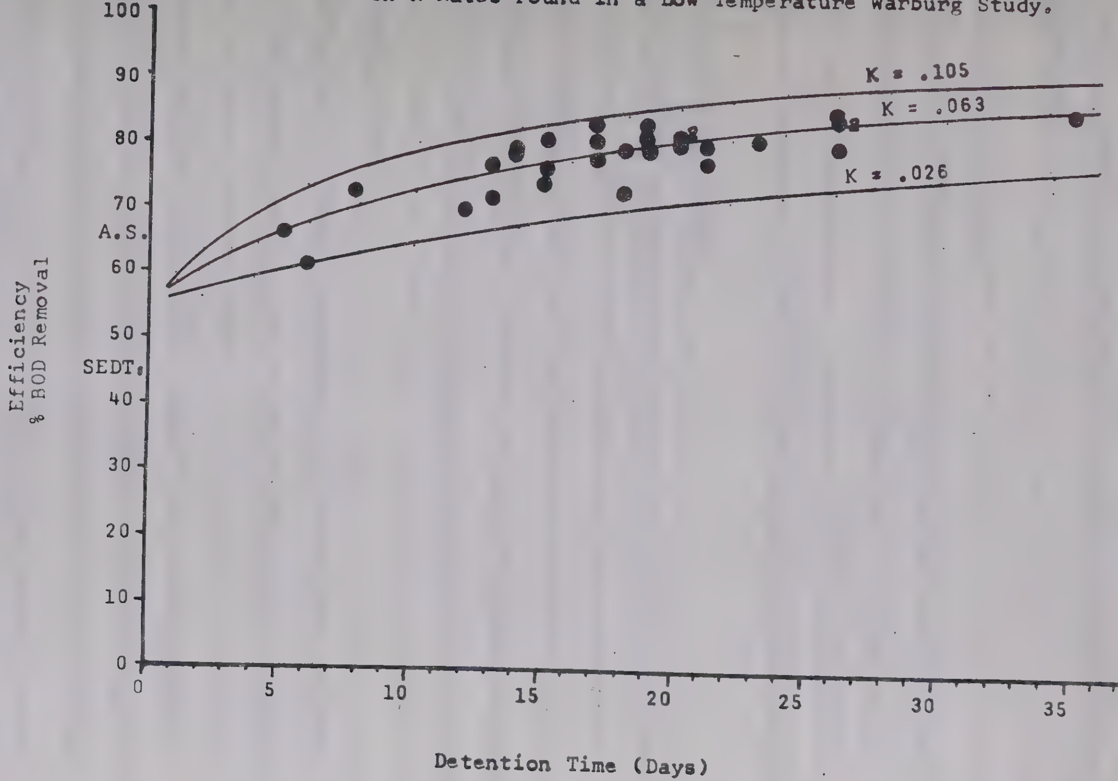


Figure 4 - Efficiencies of Alaskan Aerated Lagoons During Winter Operation at Different Loading Factors.

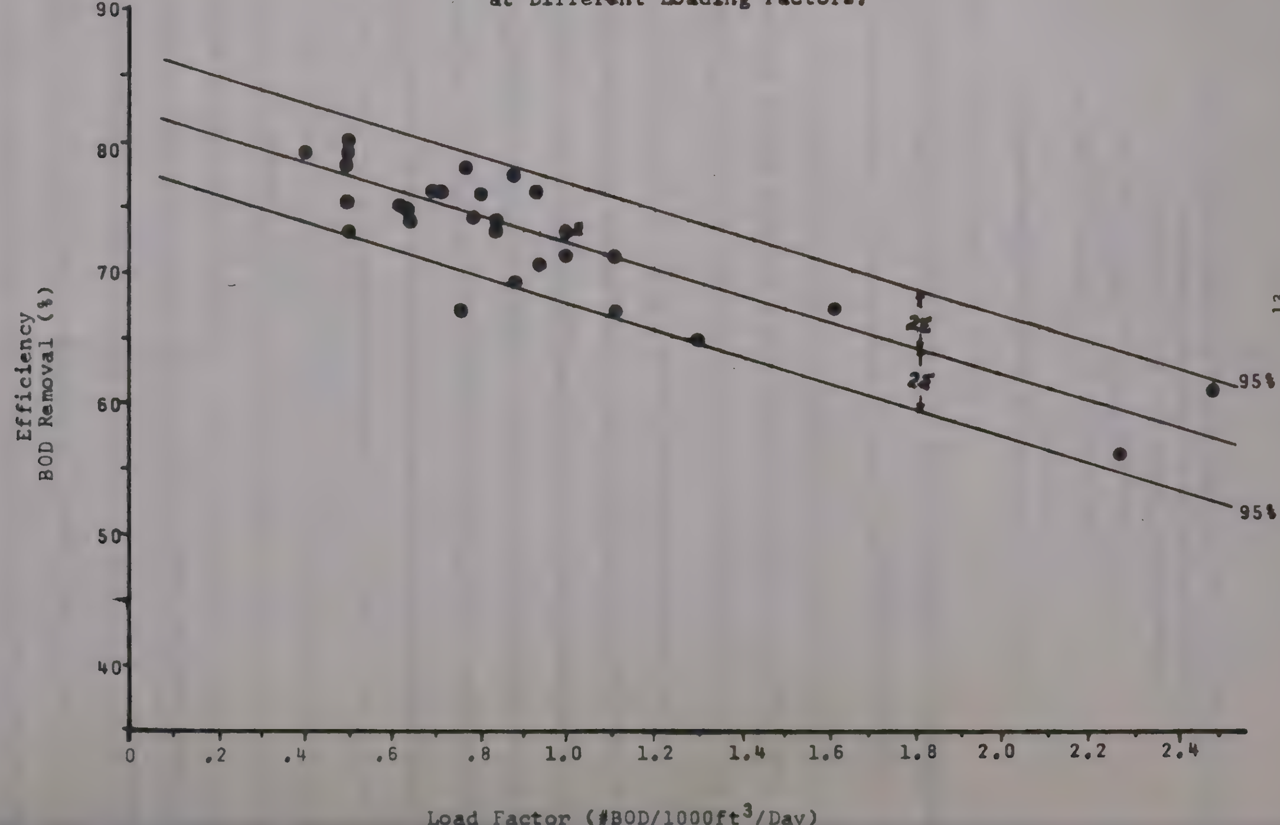


Figure 3 compares the efficiency of the aerated lagoons with detention time. All data was reduced to actual loading conditions. Ice thickness was taken into consideration in calculating lagoon volume.

Using the equation proposed by O'Connor and Eckenfelder for aerated lagoons, a plot of the theoretical efficiency for the highest, lowest, and mean values of K is also shown in Figure 3 (14).

$$\text{Efficiency} = \frac{Kt}{1+Kt}$$

Where K = Reaction Coefficient to Base e
t = detention time in days

Since the aerated lagoon is a composite system of both activated sludge and sedimentation, the efficiency of the lagoon is highly initially. The empirical efficiency is zero at zero detention time, and is assumed to reach nearly 55 percent in less than one day (see Figure 3). This assumed value is higher than the maximum 45 percent removal usually attributable to sedimentation, and lower than the usual removals by activated sludge (13, 14).

McKinney reports a mean value for BOD removal efficiencies of 63 percent with 1.7 days of surface aeration. This compares favorably with the theoretical curves shown in Figure 3. This discussion intends only to set the ground rules for the presentation of the equation which assumes an initial BOD removal of 55 percent by either or both sedimentation and activated sludge. The efficiency equation can then be modified as follows:

$$\text{Efficiency} = \frac{K\,t}{1+K\,t}\ (B) + S$$

Where B = fraction of BOD removed by biological action (45%).

S = fraction of BOD removed by sedimentation-activated sludge during first few hours of the detention in the lagoon (55%).

C. Loading Factors

Conventional lagoons have been designed using detention time BOD loading rates and/or surface loading criteria. These criteria are quite valid, since aeration and photosynthesis supply the oxygen to this type of lagoon. Because aerated lagoons do not depend on surface aeration or algal photosynthesis for oxygen, surface loading concepts are not valid. The streams, lakes and sewage lagoons in the North are covered almost entirely with ice and snow, making surface aeration insignificant. Therefore, a loading factor must be considered in aerated lagoon design. The use of the mixed liquor suspended solids-time relationship was discounted because the lagoon is not completely mixed. A concept similar to surface loading was adopted, using a BOD loading per unit volume instead of per unit surface area. Figure 4 presents the load factor-efficiency relationships for unit loadings of lagoons during winter months. Ice thicknesses have been considered in these calculations. The mean and 95 percent confidence limits are presented. As with Figure 3, normal designs would usually be based on mean values. However, if higher quality was desired, the lower limits would be used. It can be noted that the limits of Figure 4 compare favorably with the upper and lower values of K's shown in Figure 3.

D. Oxygen Requirements

The oxygen requirement of a lagoon may be estimated by the equation $R_r = a' L_r$ (15).

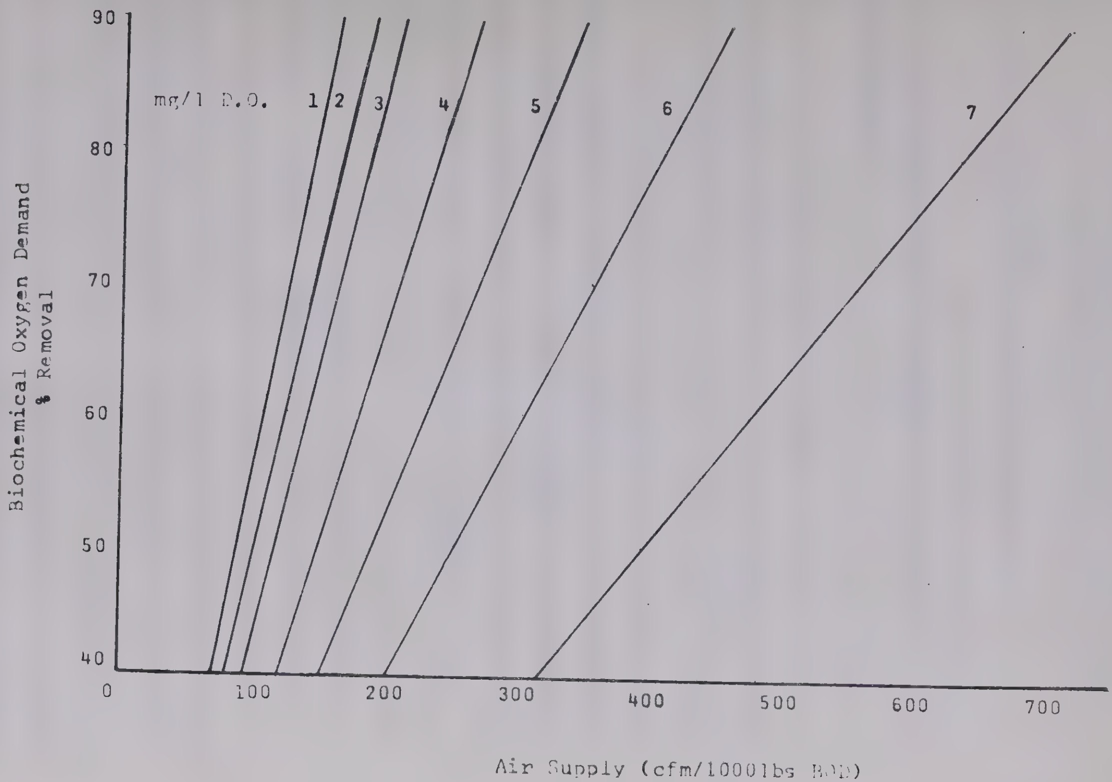
Where R_r = lbs of oxygen required to oxidize the wastes

L_r = lbs of five-day BOD removal per day

a' = ratio between oxygen utilized and BOD removal

Thimsen reports a value of 1.45 for a' in areas where K approaches 0.1 (16).

Figure 5 - Air Requirements for Aerated Lagoons for Different Levels of Efficiencies and Dissolved Oxygen.



The K values found in the cold temperature study were from 0.026 to 0.105, making the value of 1.45 a good approximation. An average value for a' was calculated from the Eielson pilot lagoon data to be 1.49. These values are not significantly different. However, the use of 1.49 gives a better fit of experimental and theoretical values, and is therefore recommended for arctic and subarctic designs.

Normally in aerated lagoon design an allowance is made for surface aeration, but with ice cover all oxygen transfer must come from diffusers.

The air required is dependent on temperature, dwelling time, bubble size, dissolved oxygen content, and many other factors that affect the efficiency of oxygen transfer. Figure 5 gives air requirements per 1000 lbs of ultimate BOD at different levels of dissolved oxygen for a lagoon 10 feet deep, supplied with air from Air Aqua diffusers feeding two cfm of air per 100 feet of tubing, the air being close to 0° C at bubble point.

E. Air Distribution

The lagoon data along with the theoretical calculations show that 86 percent of the BOD removal occurs in the first 1/3, and four percent in the last 1/3. Therefore, the allocation of air to the lagoon should be based on this information. For longer or shorter detention times, the information may be extrapolated from Figure 3.

Pending further research, it is recommended that air lines be spaced as follows. Since the activated sludge will settle near the inlet, the inlet tubing should be spaced at 2.5-foot intervals to a distance equivalent to two days' detention from the inlet; at five-foot intervals throughout the rest of the first 1/3 of the lagoon; at 10-foot intervals in the second 1/3 of the lagoon; and at 20-foot

intervals in the remaining 1/3. A quiescent zone, 40 feet from tube to tube, should be allowed between the second and third segments to permit some of th motile algal forms and suspended solids to settle to the bottom. This spacing will also provide the necessary oxygen for both sludge digestion and oxidation of the waste.

F. Geometric Configurations

Generally, the surface configurations of the lagoon should minimize heat loss. The direction of the flow in the lagoon may dictate a slightly different configuration to prevent short circuiting and to give maximum aeration. A third consideration is the available lengths of plastic tubing, to avoid tubing splices in the system.

Field observations at Eielson using fluorescent dye of a clear plastic model lagoon at Regina, Saskatchewan, indicated that the flow in the lagoon is along the air lines before flow crosses into the next air cell. Short circuiting appeared to be insignificant. Somewhere between the 1/3 and midpoint of the lagoon, a baffle should be installed to prevent floating solids from blowing or drifting to the part of the lagoon and reducing aeration. Care should be used to prevent ice action from jacking the baffles out of the lagoon.

G. Recirculation of Water

Recirculation of water from the cells near the outlet of the lagoon to the primary cell is necessary only when the water is high in sulfate content, which tends to be difficult to stabilize, or when the influent contains an industrial waste of high BOD. The amount of water recirculated should be sufficient to reduce the BOD of the influent to 400 mg/l (17).

I. Construction of Side Slopes and Bottoms

Side slopes of the aerated lagoon should be steeper than in the conventional sewage lagoon in order to reduce the surface area. One-on-three slopes is acceptable. The angle of slope should not exceed the natural angle of repose for the soil unless stabilization is provided.

A minimum berm-width of ten feet is desirable to permit access by maintainance vehicles. A minimum two-foot free-board is advisable on the dikes. For lagoons over 25 acres log booms or rip-rap may be needed to prevent dike erosion from wave action.

The lagoon bottoms should be graded as level as possible and should not vary more than 1/2 foot in elevation across the bottom. The bottoms and side slopes should be treated to prevent water from leaking from the lagoon. This waterproofing can be accomplished by spreading and compacting soil cement mixtures, by using a membrane such as bituminous asphalt or polyethylene, or by using bentonite. Care should be taken with membrane type of construction so that enough soil covers the membrane to prevent damage. When the membrane is damaged, subsequent digestion of sludge under the membrane produces large gas bubbles causing the membrane to rise.

Lagoons can be built on permafrost if care is taken in design. As the heat content of a lagoon is large, it will naturally thaw a large bulb of earth under the lagoon bottom. The lagoon at Northway has vertical sides and is in permafrost. Anchors were installed in the soil to hold the side walls during backfilling. The Bethel lagoon has sloped sides and is in permafrost. Here the lagoon melted an old iced drainage ditch and emptied. The dike had to be repaired.

I. Sludge Accumulation

Sludge accumulation is another important consideration in the aerated lagoon. In the Eielson lagoon, sludge accumulated in the last two-thirds of the pond at a rate of approximately one-quarter to one-half inch per year, and in the first quarter of the lagoon at the rate of approximately one-half inch per year. During extreme cold, the oxygen uptake rate of the sludge is quite low and anaerobic digestion is quite slow. When the temperature of the lagoon approaches $10^{o}C$ in the spring, the sludge on the bottom starts to digest, and some sludge rises to the top of the lagoon. Usually the air pattern will cause the sludge to break up within a matter of several days, and odors have been noticed only when the sludge has accumulated for some time in a corner of the lagoon. When sludge floats to the corners of the lagoon, it should be broken up so that it will sink.

J. Inlet Structures

If the effluent enters the lagoon above the water surface, a heat tape should be installed to prevent glaciation in the lines. Where lift stations are used to pump waste into the lagoon above the surface, the pipe should be sloped back to the lift station rather than allowing the water to drip out, causing glaciation. It is preferable, however, that the inlet lines enter beneath the lagoon surface in order to get better dispersion of solids. If pipes will be subjected to freezing temperatures either above or below the ground, a source of adequate heating should be available. The optimum system should include on-line instrumentation to indicate power failure to or in these lines.

K. Effluent Structures

The effluent structures of the lagoon should be designed to withdraw the effluen

from at least 4.5 feet below the surface of the lagoon, and should be sufficiently insulated to prevent ice build-up during the winter months. Heat losses and freezing which will occur between the effluent structure and the receiving stream must also be considered, since waste water from the lagoon will have given up most of its heat energy. A suggested effluent structure is shown in Figure 6.

The effluent line should rest on a two-square-foot concrete apron to reduce erosion of the toe of the dike.

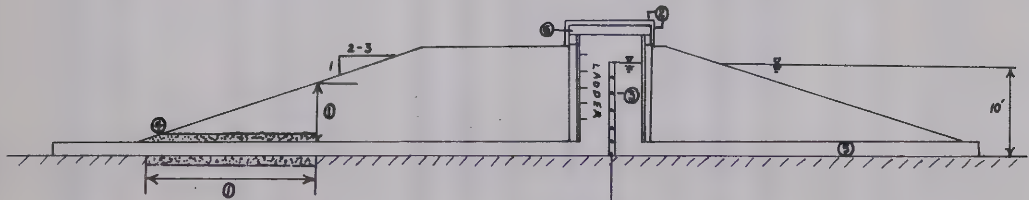
L. Plugging of Air Lines

Waters containing a large amount of sulfates or carbonates may cause the air lines to plug after six months to a year of operation. A section of plugged tubing from the Cordova aerated lagoon was examined by the author. The material plugging the slits in the tubing was a carbonate material easily dissolved with hydrochloric acid. Originally dilute hydrochloric acid solution was used to clean the system, but there was some difficulty in getting this solution to the ends of the lines. The introduction of concentrated hydrochloric acid using a hypochlorination type of injection pump has been moderately successful.

The latest system introduces anhydrous hydrogen chloride gas directly into the compressed air lines through a stainless steel regulator and injection valve. The manufacturer reports that this is the most effective method for unplugging these lines (17).

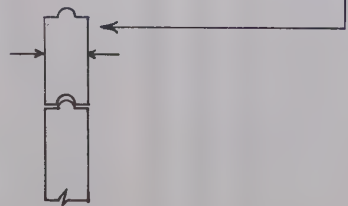
Whatever the method used, adequate safety precautions for handling the hydrogen chloride gas or the acid solution should be observed. Industrial safety manuals give the proper standards.

FIGURE 6. SUGGESTED EFFLUENT STRUCTURE



(1.) Insulate with styrofoam to help prevent icing. Length of insulation to be determined by depth of annual frost penetration in soil.

(2.) Manhole and top insulated to prevent freezing. Protect insulation from frost heave along sides.



Detailed Stop Logs

(3.) Adjustable stop logs caulked to prevent leakage. Stop logs should be placed in slots to permit changes of lagoon elevation. Clearance should be provided for removal of logs from manhole.

(4.) Install heat tape around outlet pipe for a distance of 10 feet under toe of dike for emergency thawing.

(5.) Outlet pipe sized to handle hydraulic flow of lagoon.

(6.) Manhole should be sized for easy access.

L. REID 5/67

e cleaning system should be set up to be controlled by the operator. A sug-
sted cleaning schedule is presented later in this report.

. Air Compressors

e air compressor should be the rotary-positive type manufactured by a reput-
le company. A standby compressor and motor should be included in all sys-
ms to cover power and equipment failures and to provide aeration during
aintenance shutdowns. Again, heat tapes should be considered if this line is
bjected to freezing temperatures, since water may enter the line as a result
power failure or during maintenance.

Housing of Equipment

e air compressors and allied electrical controls should be housed in a weath-
-tight structure that is properly vented for intake air. The structure should
ovide easy access to the equipment. Its size may vary from a doghouse-type
ructure with removable lid to a small building. If metal buildings large enough
enter are used, insulation should be installed to deaden the sound. An intol-
able noise level was noted by the author in the metal buildings at the Regina
goon.

Algae

ere has been considerable interest in the effects of algae in the lagoon. The
mbers of algae will be dependent on the amount of food available. Where
adings are relatively light, the algal populations will be reduced. A properly
signed effluent structure will severly limit the amount of algae that will reach
e receiving stream.

Ice

Ice can be expected to form in the lagoon at thicknesses up to four feet in certain locations. Normally, the ice on the first half of the pond will range in thickness from zero to one foot. Anchor ice along the edges may be several feet thick. Ice on the second half of the lagoon may be up to four feet thick if snow is permitted to drift onto the pond. The snow causes the existing ice to sink, resulting in the formation of a snow-ice mixture.

Q. Post Chlorination

The current water quality standards for Alaska require the chlorination of the pond effluent before discharge into some streams. At low temperatures the reaction rate of chlorine is greatly reduced, so that longer contact times are necessary. If chlorination is required, chlorination chambers should be constructed at the effluent structure. The required safety precautions for the handling of chlorine should be considered in the design.

DESIGN TECHNIQUES

The trend is for pollution control agencies to upgrade the standards of treatment. A high level of treatment should be instituted initially, since it is more economical to build a larger waste treatment plant to begin with than to enlarge the plant later, or to build a new plant, to meet improved criteria.

A set of design factors has been developed for aerated lagoons located in the Arctic and Subarctic. These should be thought of as guidelines until research further defines the biological regime of the lagoon and refines the guidelines for air requirements and spacing of aeration lines.

Design of a sewage treatment system should start with a survey to determine th quantity and quality of the proposed receiving waters. The conditions of the

ceiving waters may well dictate the amount of design sophistication. Ideally, e data on the receiving body should be collected for at least one full year, or survey should be made during each season of the year. Particular attention ould be paid to late winter, and to early-spring conditions before breakup. hese are the times when natural pollution has reduced the oxygen concentra- on of the water. Any significant oxygen demand at that time may cause fish lls and obnoxious odors. Lagoons for the Arctic and Subarctic should be esigned around winter conditions.

he volumes and five-day 20° C Biological Oxygen Demand of the sewage must determined to size the lagoon properly. The cost of making these measure- ents is small and less costly than over- or under-design based solely on stimates.

thorough soil analysis should be made, including permeability in the thawed ate. Since warm weather will degrade the permafrost, the structural con- guration of the lagoon must be designed to reduce the effects on the pond when awing occurs. A vertical-sided lagoon built on permafrost may fail when the round is thawed, and a soil impermeable when frozen may be permeable when awed.

everal designs are considered, based on different local circumstances and equirements. Discussion of calculations familiar to a person knowledgeable design, and information readily obtained from manufacturers' catalogs, have een omitted for the sake of brevity.

ase I. Small town with sewers, but no treatment system.

. Basic Information

AHRC REPORT NO. 102 - ERRATA SHEET

1. Population - 2000.

2. Average 5-day, $20^\circ C$ BOD test of composite sewage = 208 mg/1.

3. Sewage flow of 160,000 gpd.

4. Regulations require the effluent not to exceed 50 mg/1 5-day, $20^\circ C$ BOD and a DO level of not less than 5 mg/1.

5. Ice on lakes normally freezes to 2-foot depth.

B. Lagoon Dimensions

1. Efficiency = $\frac{\text{BOD in} - \text{BOD out} \times 100}{\text{BOD in}}$

$$= \frac{208 - 50}{208} = 76\%$$

See Figure 4. At 76% removal the mean load factor (middle line) would be 0.67 #BOD/1000 ft^3/day.

2. Detention time

$$\#\text{BOD/day} = \frac{\text{Flow (mgd)} \times \text{BOD} \times 8.34\#/\text{gal}}{1,000,000}$$

$$\text{Detention time (days)} = \frac{\#\text{BOD/day} \times 1000 \times 7.48\ \text{gal/ft}^3}{\#\text{BOD/day}/1000\ \text{ft}^3 \times \text{flow gpd}}$$

The entire equation can then be reduced to:

$$\text{Detention time (days)} = \frac{\text{BOD (mg/1)} \times 62.4\#/\text{ft}^3}{\text{Load factor } (\#\text{BOD}/1000\ \text{ft}^3/\text{day}) \times 1000}$$

$$\frac{208 \times 62.4}{.67 \times 1000} = 19.8 \text{ or } 20 \text{ days}$$

Return to Figure 3. Enter at 20 days and go vertically until the K = 0.063 line is reached and then go horizontally to the left. The efficiency based on detention time is 80 percent.

3. Lagoon Dimensions

Ice depth = 2'

For 10' deep lagoon ice could equal 20%

$$\text{Volume } (ft^3) = \frac{\text{Daily flow (gpd)} \times \text{Detention time (days)}}{7.48 \text{ gals}/ft^3 \times \text{Ice factor}}$$

$$= \frac{160,000 \times 20}{7.48 \times 0.8} = 534,759 \ ft^3$$

$$\text{Area} = \frac{\text{Volume}}{\text{Depth}} = \frac{534,759}{10} = 53,476 \text{ or } 1.2 \text{ acres}$$

For vertical sides, dimensions could be as follows:

2 cells at 125' x 214'

C. Air Requirements - see Figure 5

Enter at BOD removal equals 76%. Move horizontally until 5 mg/l DO line is intersected, then vertically downward to the Air Supply, reading 270 cfm per 1000 lbs of BOD loading.

$$\text{BOD loading} = \frac{\text{flow (gpd)} \times 8.34\#/\text{gal} \times \text{BOD strength mg/l}}{1,000,000}$$

$$\text{Air required} = \text{loading (lbs)} \times \frac{\text{Factor from Figure 5}}{1000}$$

$$= \frac{277.6 \times 270}{1000} = 75 \text{ cfm of air}$$

D. Length and spacing of air diffuser tubing. Figure 5 is based on a distr-ibution of 2 cfm air/100 ft of tubing at a depth of 10 feet.

$$\text{length of tubing} = \frac{75 \text{ cfm} \times 100}{2 \text{ cfm}/100 \text{ ft}} = 3750 \text{ ft}$$

The allocation of air or tubing length should be as follows:

first 1/3 at 86% x 3750 =	3225
second 1/3 at 10% x 3750 =	375
third 1/3 at 4% x 3750 =	150
	3750 ft

Case II

A. Same as Case I except BOD of effluent must not exceed 50 mg/l more 5% of the time (bottom line - Figure 4)

B. Efficiency = 76%

Load factor = 0.21

$$\text{Detention time} = \frac{208 \times 6214}{1000 \times .21} = 62 \text{ days}$$

Using the low value on the curve of K = 0.026 found in the study and calculating the removal efficiency at 62 days, efficiency comes close to the predicted 76%.

$$\text{Efficiency} = \frac{Kt \times B}{1 + Kt} + S$$

$$E = \frac{1.26}{2.26} \times (.45) + 55\% = 80\%$$

$$\text{Volume} = \frac{160,000 \times 62}{7.48 \times 0.8} = 1,657,754$$

Area = 165,775 ft^3 or 3.8 acres

Case III. Small town not on a sewage system.

A. Basic Information

1. Population - 2000 persons
2. Assume 0.17#BOD per capita per day
3. Assume 150 gpcpd
4. 76% normal removal of BOD is goal
5. 20% of lagoon depth may be ice

B. Lagoon Dimensions

1. Detention time - load factor same as in Case I (0.67#BOD/1000ft^3/day)

#BOD/day = population x 0.17#BOD/person/day

= 2000 x 150 = 300,000 gal

$$\text{Detention time} = \frac{\#BOD/day \times 1000 \times 7.48 \text{ gal}/ft^3}{\#BOD/day/1000ft^3 \times \text{flow (gal/day)}}$$

$$= \frac{340 \times 7.48 \times 1000}{.67 \times 300,000} = 12.6 \text{ days}$$

From Figure 3 at 12.6 days, efficiency is 76%.

A 13 (12.6) - day detention time will give about 75 percent efficiency (Figure 3) as opposed to the desired 76 percent. The more conservative design

ıld be chosen, for 20 days, from Figure 3. The volume calculated on the lay detention time is presented below for comparison.

$$\text{Volume } (ft^3) = \frac{\text{days detention x daily flow x gal/days}}{7.48 \text{ gal/ft}^3 \text{ x ice factor}}$$

$$\text{Volume} = \frac{12.6\ (300,000)}{7.48 \times 0.8} = 631,648 \text{ ft}^3$$

$$\text{Area} = \frac{\text{Volume}}{\text{Depth}} = \frac{631,648}{10} = 63,165 \text{ ft}^2 \text{ or } 1.45 \text{ acres}$$

CUSSION OF DESIGN METHODS

e III shows that if the sewage is weak, in this case 136 mg/l, the design ed on a load factor may be considerably smaller than if the sewage is of rage strength. Conversely, if a sewage is very strong, the detention time y be very long. The designer must select the governing criteria. Usually most conservative value is the best.

ole 3 compares the three designs. It also points out the cost of confidence design. Most designers will probably wish to follow the mean design values; vever, in some cases this may not be possible.

Table 3 - Comparison of Three Aerated Lagoon Designs

	Case I	Case II	Case III
pulation served	2000	2000	2000
rength of sewage (mg/l)	208	208	136
ily Flows (gpd)	160,000	160,000	300,000
etention time *(days)	20	62	13
agoon size (acres)	1.2	3.8	1.5
difference from Case I esign	-0-	216	25

* Ice storage not considered

MAINTENANCE

A. Snow Removal

During the winter, snow should be kept away from the compressor housing to allow access for maintenance. The inlet and effluent lines should be checked daily for ice buildup and restriction of flow.

B. Preventive Maintenance

The compressors, motors, and lift stations should be inspected daily for prope operation. A routine preventive maintenance schedule should be set up to allow servicing as outlined by the manufacturer. The lagoon air lines should be cleaned in the spring and fall. April and October are suggested for this. The gas method is recommended since it is the most efficient.

C. Dike Maintenance

The slopes of the dikes should be kept neatly mowed and cleared of trees. Grass trimmings should be removed from the lagoon edges to reduce mosquito and odor problems. Plants should not be allowed to grow along the edges of the lagoon since they provide mosquito harborages and entrap sludge. Muskrat and other burrowing animals must be kept out of the lagoon since they may undermine the dike.

The side slopes should be inspected for leakage at least weekly during the ice-free months.

D. Fencing

It may be necessary to fence the lagoon with a high link-chain fence to keep unauthorized persons and animals out of the lagoon. Ducks and moose have been observed feeding in the lagoon at Eielson Air Force Base, and children

naturally curious and may be drawn to the lagoon site.

EAS OF FURTHER STUDY

e design criteria presented in this report are necessarily empirical because the lack of certain information which may be significant. Additional research needed to completely explain why these systems work. Suggested areas of ther study are as follows:

1. Development of a better oxygen transfer relationship to allow the designer to space aeration tubing more efficiently.

2. The possibility of nesting the lagoon cells in a module arrangement to allow better flow control and possibly increase efficiency.

3. Evaluation of other types of aerating devices.

4. Acquisition of a better working knowledge of lagoon dividers to determine whether using modules would negate this need.

5. A study of inlet structures to determine better methods of dispersing sludge throughout the primary cells, giving a better activated sludge effort.

6. An extensive study of the biological life in the lagoons to better identify the contribution of living organisms to the treatment of wastes. Results of such a study would directly affect most other design factors.

7. Use of tube or plate settling devices to exclude algae and other solids from the lagoon effluent.

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